Unit 3 Nuclear Power Plant Accidents

In this unit you will learn:

- Basic operating principles of a nuclear power plant.
- Types of nuclear power plant accidents and plant safety features.
- Offsite consequences of nuclear power plant accidents and resultant protective actions.

INTRODUCTION

To many, the term "nuclear power plant accident" brings to mind the accidents that have occurred at the Three Mile Island and Chernobyl sites. The purpose of this unit is to provide information concerning methods used to minimize the possibilities for these accidents and actions to be taken to minimize their effects on the public.

Virtually all commercial nuclear power reactors in the United States are either pressurized water reactors (PWRs) or boiling water reactors (BWRs). These types of reactors are called light water reactors (LWRs) because the reactor core is covered with water to allow the nuclear reaction to take place and to keep the core cool. This unit discusses primarily accidents at light water reactors.

This unit is divided into three major sections: Operating Principles of Nuclear Power Plants, Power Plant Accidents, and Offsite Protective Actions. Each of these sections contains information that can be used to respond appropriately to a nuclear power plant accident.

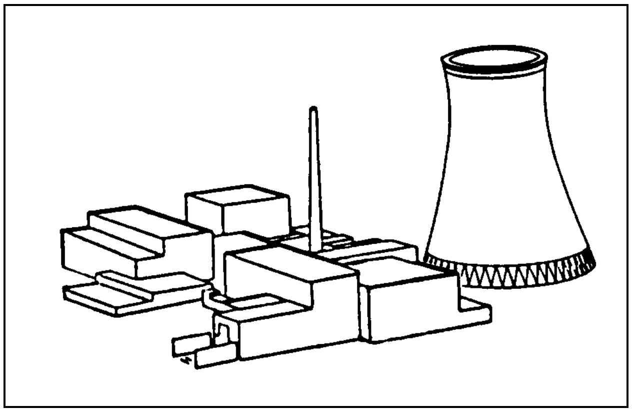
The **Operating Principles of Nuclear Power Plants** section describes how power plants generate electricity. The major processes and components of U.S. nuclear plants are examined.

The **Power Plant Accidents** section describes the design philosophy used for U.S. nuclear plants, some accidents that have occurred, and the effect on the public of those accidents.

The **Offsite Protective Actions** section describes protective actions detailed in the formal emergency plans required for each commercial nuclear power plant in the U.S. These actions are based on minimizing public exposure from a radioactive "plume" and from ingesting radioactive material into the body.

OPERATING PRINCIPLES OF NUCLEAR POWER PLANTS

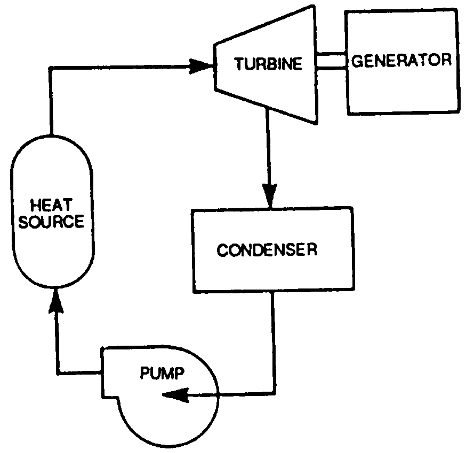
A nuclear power plant is a facility at which energy released by the fissioning of atoms is converted to electrical energy under strictly regulated operating conditions. The major processes are the same as those in nonnuclear (conventional) power plants except that the coal or oil fired boiler is replaced by a nuclear reactor.



Electric Power Plant

In each plant, whether nuclear or fossil-fueled, the following basic components are present:

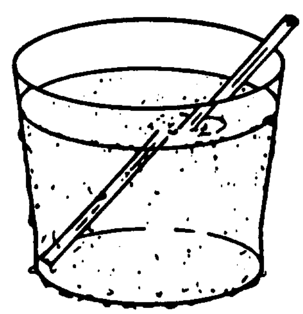
- **Heat source:** Provides heat to generate steam. In a nuclear power plant, the heat source is the nuclear reactor, often referred to as the reactor core.
- **Turbine/generator:** Uses the energy of the steam to turn a turbine/generator that produces electricity.
- **Condenser:** Condenses the steam back to water so that it can be returned to the heat source to be heated again.
- **Pump:** Provides the force to circulate the water through the system.



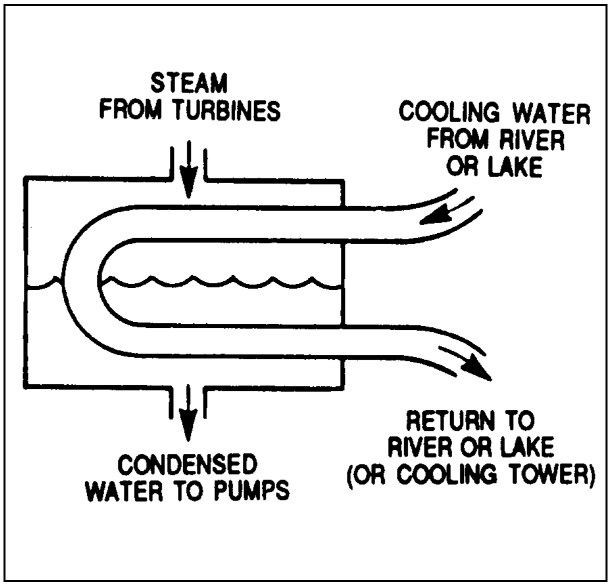
Basic Plant Components and Process

Cooling Water

Just as water vapor condenses on a cool drinking glass on a warm day, a power plant's condenser uses a cool surface to condense the steam from the turbine. This cool surface is provided by cooling water pumped from a nearby water supply such as a river, lake or ocean.

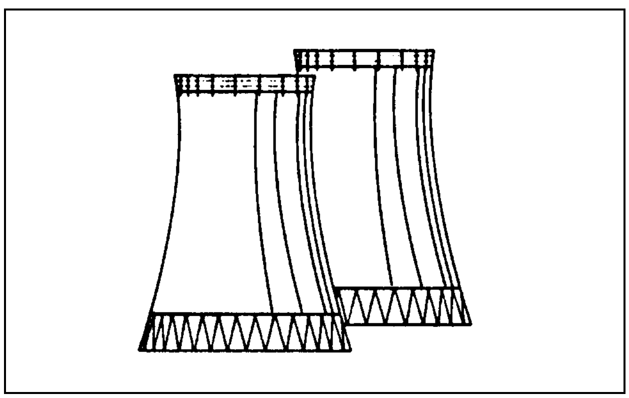


Cold Glass with Condensation



Power Plant Condensation

The water used to cool the condenser is slightly warmer after use. For this reason, a **cooling tower** is sometimes used to prevent a harmful temperature rise in the water supply. A cooling tower is a large heat exchanger. This heat is carried up the stack and is visible as water vapor. Cooling towers are used at many large nuclear as well as non-nuclear power plants. Because cooling towers are part of a nonradioactive system, no radioactive material is released from them.

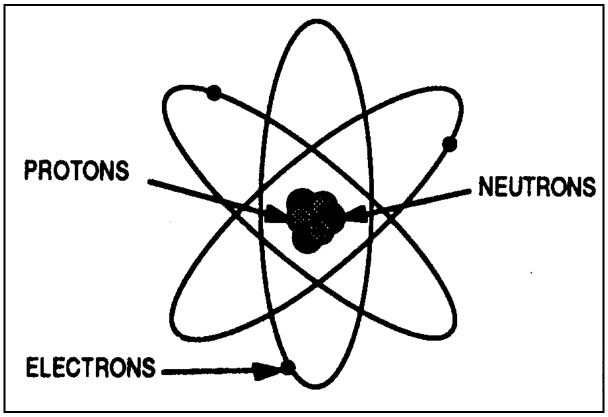


Cooling Towers

Nuclear Reactors

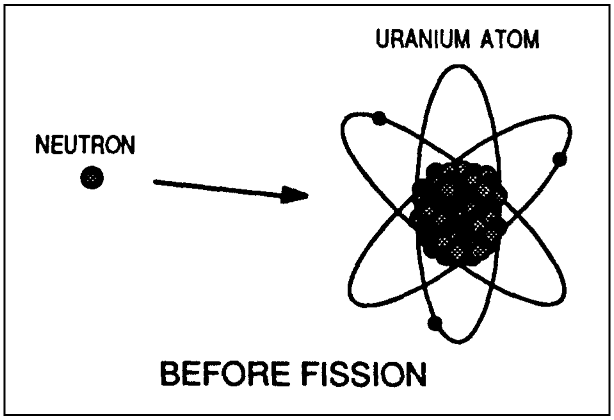
The source of heat in a nuclear power plant is the **reactor core**. A nuclear reactor generates heat through a controlled nuclear reaction. The commercial nuclear reactors used today splits **uranium atoms** to produce heat.

Uranium atoms, like other atoms, consist of neutrons, protons and electrons. As you have learned, protons and neutrons are small particles found in the atom's nucleus. Electrons are even smaller particles which orbit the nucleus.

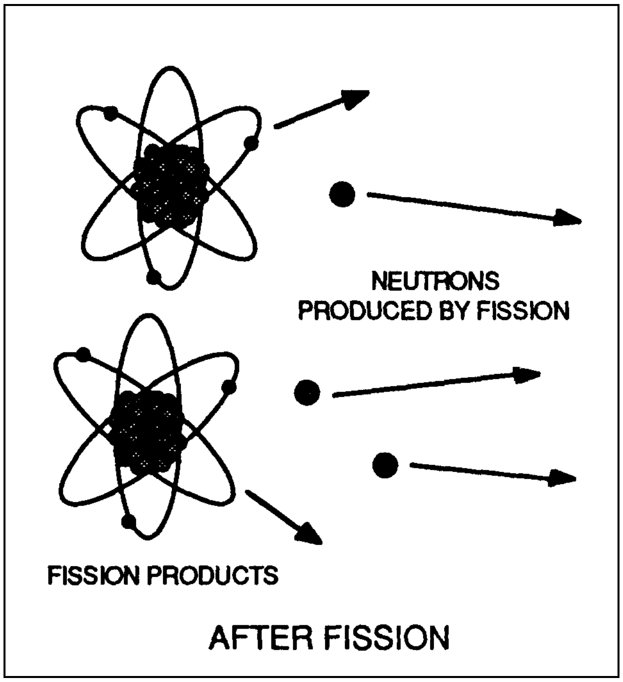


Atom

When a uranium atom is struck by a free neutron, it may split into two or more atoms called “fission products". The process of splitting an atom is called "fission." The fission process is accompanied by the release of energy, including heat and one or more neutrons.



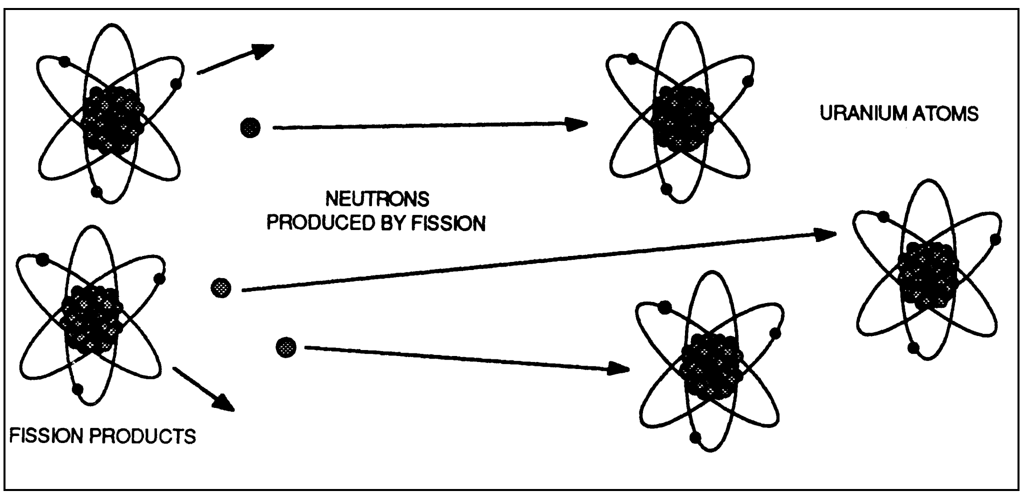
Neutron Approaching a Uranium Atom



Fission Products and Neutrons

The fission of one atom releases only a very small amount of energy. However, if other uranium atoms are located near a fissioning uranium atom, they may be struck by one or more of the neutrons released by the fission reaction. This may result in a chain reaction involving a tremendous number of fissions and great amounts of energy.

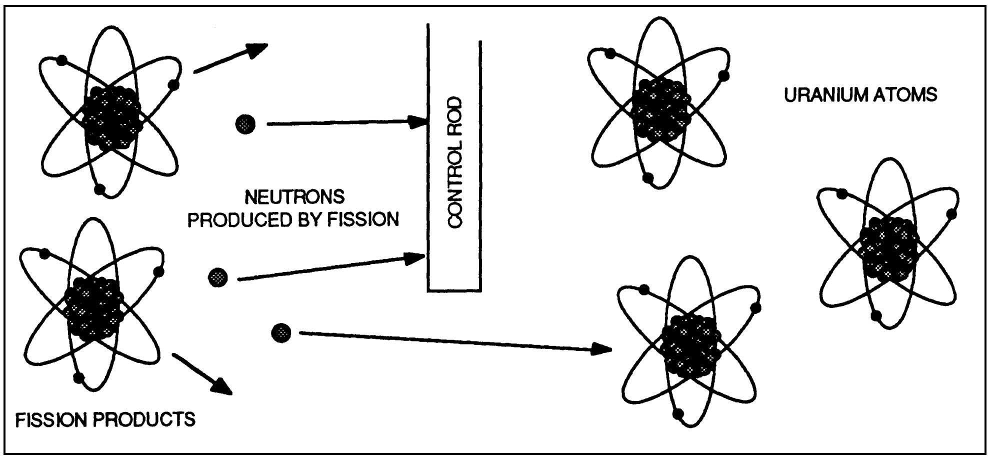
Nuclear weapons and nuclear reactors are designed differently and contain different amounts of fissionable materials. Consequently, a reactor cannot explode like a nuclear bomb.



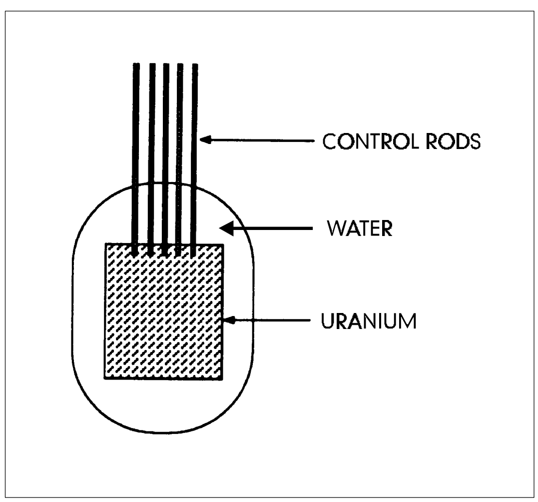
Fission Chain Reaction

The nuclear chain reaction may be controlled using a device called a **control rod**. Control rods are made of materials which absorb neutrons. Thus, when a control rod is inserted into a nuclear reactor it reduces the number of free neutrons available to cause the uranium atoms to fission. When all the control rods are inserted into the reactor, it is called a reactor shutdown. Sometimes all the control rods will be inserted quickly due to a safety or emergency condition. This is known as a **scram**.

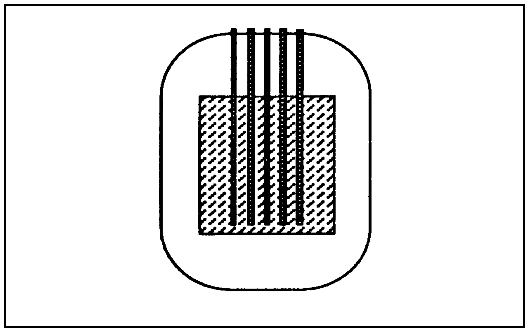
The nuclear chain reaction is also affected by the water in the core. All light water reactors (LWR) require the core be covered with water for the chain reaction to be allowed to continue. Therefore if there was an accident that resulted in loss of the water covering the core the reactor would scram.



Control Rods Absorb Neutrons to Prevent Fissions



Control Rods Withdrawn



Control Rods Inserted

Fission Products

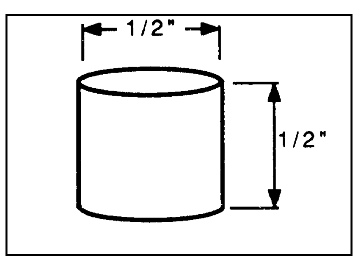
The smaller atoms produced by nuclear fission are called fission products. Fission products may be of a wide variety of elements. Common fission products include xenon, krypton, iodine, cesium and strontium. Most fission products are highly radioactive and will undergo radioactive decay. Most decay quickly and will be gone within several days. Some, however, remain in the nuclear fuel for many years, and must be contained to prevent injury to the public.

Decay also produces heat, referred to as decay heat, that must be removed even after the reactor is shut down. If the decay heat is not removed, it will result in failures of the barriers designed to contain the fission products and possibly a radioactive release from the plant.

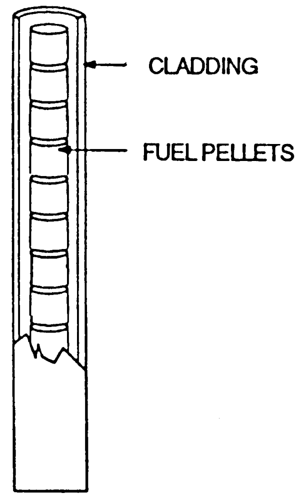
Nuclear Fuel

The nuclear fuel typically used in nuclear power plants consists of uranium in the form of uranium dioxide (UO^2). Uranium dioxide, a ceramic, is used because like all ceramics, it can withstand very high temperatures. The uranium dioxide is fabricated into cylindrical **fuel pellets**, approximately one-half inch long.

Many fuel pellets are stacked end-to-end to form a **fuel rod**. Each fuel rod is approximately 12 feet long and is encased in a metal tube called the **fuel cladding**. The purpose of the cladding is to prevent fission products from escaping from the fuel pellets into the reactor cooling water. Most radioactive fission products remain in the fuel, very close to where they are formed. However, certain fission products such as krypton and xenon gases or iodine atoms are mobile and may move out of the fuel and become trapped in the narrow gaps between the fuel pellets and the fuel cladding.

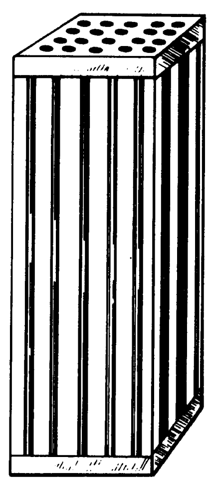


Uranium Fuel Pellet



Fuel Rod With Pellets and Cladding

A number of fuel rods are grouped side-by-side to form a **fuel assembly**. A number of fuel assemblies are in turn grouped together to form the nuclear **reactor core**. A large modern nuclear power reactor core is approximately 12 feet (3.7m) long and 12 feet in diameter, with approximately 200 fuel assemblies.



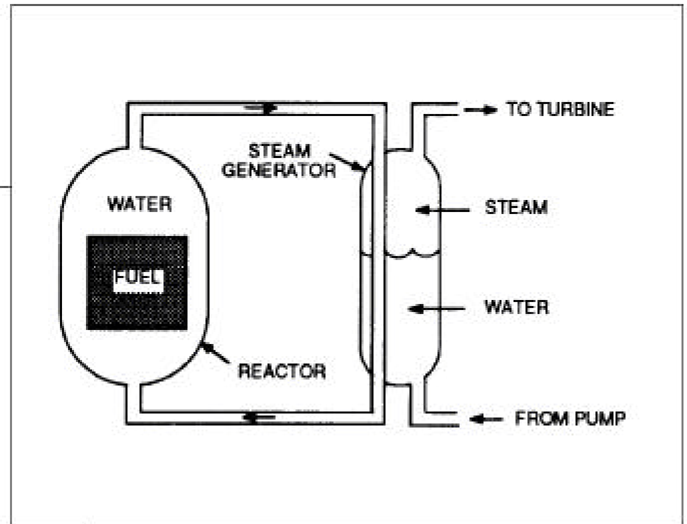
Fuel Assembly

Heat generated in the reactor is removed by **reactor cooling water**. Reactor cooling water is circulated, through the length of the reactor core, between the various fuel rods. The system that contains the reactor cooling water is called the **primary coolant system**.

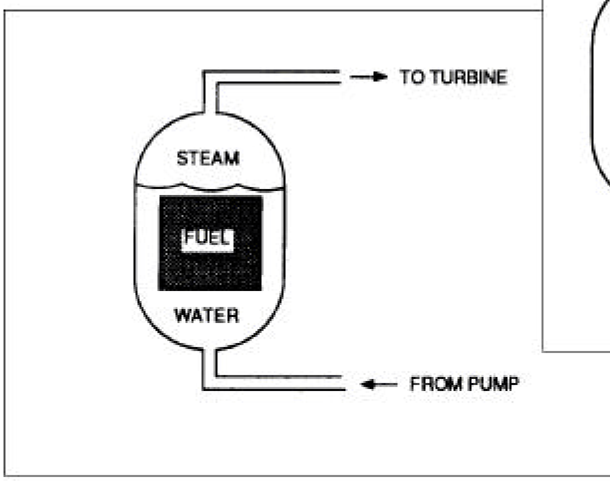
Types of Reactors

There are two main types of commercial nuclear reactors used in power plants in the United States:

- Boiling Water Reactors (BWRs).
- Pressurized Water Reactors (PWRs).



Pressurized Water Reactor (PWR)



Boiling Water Reactor (BWR)

In Boiling Water Reactors (BWRs), water (primary coolant) is allowed to boil directly in the reactor core. The boiling water generates steam which is drawn away from the reactor and used to rotate the turbine, which in turn generates electricity via the generator. Even in non-emergency conditions this water may contain small amounts of radioactive fission products.

In Pressurized Water Reactors (PWRs), the water (primary coolant) in the reactor core is prevented from boiling by being maintained at a much higher pressure. Heat is removed using a **steam generator**. In a steam generator, the primary coolant flows through a series of metal tubes while secondary cooling water flows around the tubes. In this way, heat is transferred from the slightly radioactive primary coolant system to the nonradioactive secondary coolant system. The secondary coolant is maintained at a much lower pressure than the primary coolant.

Thus, as the heat is transferred, the secondary coolant flashes to steam. This steam is then drawn from the steam generator and used to rotate the turbine generating electricity.

In addition to the PWR and BWR systems discussed above, there are several other types of systems in use, or under development, throughout the world. Although stringent regulations govern the operation of all nuclear power plants, there will always be a possibility for some type of accident to occur. The following section of this unit deals with the very real issue of how the public is protected from an accident should one occur at a nuclear power plant.

Practice Exercise

20. Major components which may be found at coal and oil burning power plants as well as nuclear plants include ________________, ___________________, ___________________, and ________________.

21. A structure used to prevent harmful temperature increases in lakes and rivers is a _____________________.

22. The fuel used at nuclear power plants is made from __________________.

23. When an atom of nuclear fuel is struck by a free neutron, it fissions yielding ________________,_________________, and _______________________.

24. The number of neutrons available to cause further fissions is governed by __________________.

25. The two main types of commercial nuclear reactors used in the United States are ____________________ and ________________________.

POWER PLANT ACCIDENTS

Nuclear power plants are designed with two principal safety objectives in mind:

1. To contain fission products to prevent offsite health effects.

2. To ensure that heat generated by the reactor, including heat generated by the decay of fission products after reactor shutdown, is removed.

If the decay heat is not continually removed from the reactor following shutdown, this heat could cause failures of the system designed to contain the fission products. The fission products generated in the reactor core are highly radioactive, thus releasing significant amounts of them to the environment could be quite harmful. Great care has been taken to prevent such a release through the **defense-in-depth** approach used in the design of nuclear power plants.

Defense-in-Depth

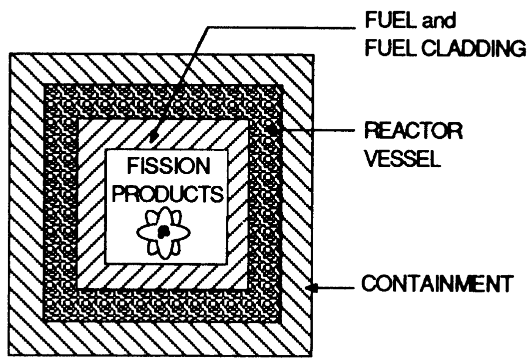
The defense-in-depth approach ensures that any release of hazardous amounts of radioactive materials will be extremely unlikely. This approach uses three barriers to prevent the release of fission products from the reactor core to the environment. These consist of:

1. Fuel rods (fuel pellet and fuel cladding).

2. Reactor vessel and primary coolant system.

3. Containment.

The chance of any single barrier failing is unlikely. The chance of all three failing simultaneously is, therefore, extremely remote.



Fission Product Barriers

Fuel Rods

The first barrier designed to prevent an inadvertent release of radioactive material from the reactor core is the nuclear fuel rod itself. During normal operations, about 99 percent of all fission products remain trapped within the fuel's structure very near the point at which they were generated by fission. The fuel cladding which encases the nuclear fuel is designed to contain the remaining 1 percent.

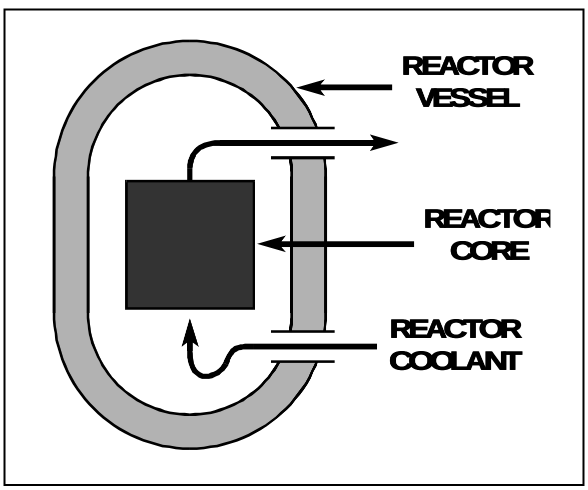
The release of fission products from the fuel rods would require a breakdown of the fuel cladding. If the core is not sufficiently covered with water to provide cooling, it could overheat resulting in a breakdown of the fuel cladding and the release of fission products in a short period of time. Additional overheating could cause the release of some of the 99 percent of the fission products normally trapped in the fuel structure. Still more overheating could cause the fuel to actually melt. This is often referred to as a "meltdown".

It does not require a "meltdown" for sufficient fission products to be released from the fuel to pose a threat. It does require loss of the many redundant systems designed to keep the core covered and cool (by removing the decay heat). These systems are designed to maintain cooling even under severe accident conditions such as a total break in the largest pipe in the system.

As discussed earlier, excess heat is normally removed from the reactor by the primary coolant system. If cooling water flow cannot be maintained, the control rods are automatically inserted into the core to stop the fission process and thus shut down the reactor (called a scram). However, the radioactive fission products remaining in the core would continue to decay. As previously stated, this decay process yields radiation and heat (called **decay heat).** To prevent increased temperatures and damage to the reactor core, the decay heat must continually be removed, even after shutdown. Numerous systems and back-up emergency core cooling systems are provided to ensure that reactor cooling water continues to flow through the reactor core to remove decay heat, even after the reactor has been shut down and the fission process has stopped. Only failure of all of these systems would allow the potential for a "severe core damage accident" or a meltdown.

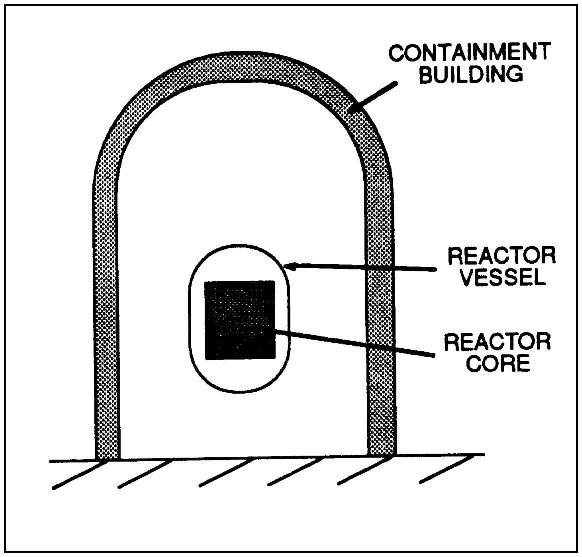
Reactor Vessel and Primary Cooling System

Even if the fuel cladding (first barrier) fails, there are two more barriers to prevent a release to the atmosphere. The second barrier designed to prevent the inadvertent release of fission products to the environment is the primary coolant system. One part of the primary coolant system, the reactor core, is located within a pressure vessel which has walls of steel up to 10 inches (25 cm) thick. This pressure vessel is called the **reactor vessel.** The primary coolant system contains within its large pipes, reactor cooling water and any radioactive materials which may be present. Failure of the reactor vessel or the associated primary coolant system piping would result in the release to the **containment building** (the third fission product barrier) of any fission products released from the fuel.



Core, Vessel, and Coolant

Containment Building



Core, Vessel, and Containment Building

The third barrier between the fission products and the environment is the containment building. The containment building is the familiar large dome-like structure which may be seen when approaching or passing many nuclear power plants. At some plants, the containment is located within a building which serves as yet another fission product barrier.

A containment building generally consists of high density, reinforced concrete as much as 6 feet (1.8 m) thick and is built to withstand not only a severe accident, but also a variety of natural and man-made hazards such as earthquakes, tornadoes, and airplane crashes.

Even if the core is severely damaged or melted (first barrier) and the primary cooling system fails (second barrier), there should be only small releases to the atmosphere because of the last fission product barrier, the containment. During the accident at Three Mile Island, there was severe core damage and some melting of the core and the primary coolant system did fail but only a small amount of fission products were released because of the effectiveness of the containment.

Although all three of these boundaries exist to prevent the inadvertent release of fission products to the environment, like all man-made things, they may fail or partially fail to perform their intended function. The failure of these boundaries may then result in the release of radioactive material to environment.

The History of Nuclear Accidents

Nuclear accidents occasionally occur, making people more concerned about the safety of nuclear power plants. Now that we have learned about the defense-in-depth measures taken in the design of nuclear power plants, we can examine some of the past nuclear power plant accidents. The most well-known nuclear power plant accidents occurred at Three Mile Island and Chernobyl. Both of these accidents involved the release of radioactive material and initiated radiological emergency management efforts. Not every accident at such plants results in public radiation exposure. Even serious accidents could occur without public exposure. Examples of some nuclear accidents which have occurred at nuclear power plants and other nuclear facilities include:

- Windscale, England (October 7, 1957). A fire at this plutonium production plant released significant amounts of radioactive material. Radioactive iodine contaminated nearby grazing land. Two million liters of milk were kept from the market. Although large amounts of radioactive material were released, no cases of acute radiation sickness occurred.

- SL-l, Idaho (January 3, 1961). Three workers were killed by an event at this small military test reactor. A control rod was ejected from the core while being manually moved by one of the workers. All three deaths were due to causes other than radiation.

- Enrico Fermi, Michigan (October 5, 1966). A partial meltdown of this reactor was caused when a component broke loose and blocked the flow of coolant. This serious accident did not result in any release of radioactive material.

- Browns Ferry, Alabama (March 22, 1975). A fire under this commercial power plant's control room was caused by use of a candle flame to check for air leaks. The fire burned the electrical cables used by plant operators to control plant equipment and to send instructions to emergency cooling equipment. This serious accident did not result in any release of radioactive material.

The worst accident at a U.S. commercial power reactor occurred on March 28, 1979 at Three Mile Island (TMI) Nuclear Station in Pennsylvania. As a result of equipment failures and human operation errors, the water level in the reactor core decreased to the point that the fuel was no longer submerged in water. Without the cooling normally provided by this water, the cladding and some of the fuel pellets melted. Large quantities of radioactive materials were released into the containment building. The containment building performed as it was designed. The radioactive releases to the atmosphere that occurred during the TMI accident were very small and resulted primarily from leaks in systems that were required to operate during the course of the accident. These systems carried water that contained very large amounts of fission products outside the containment and some leaking could not be prevented.

With all of the care and precautions involved in the defense-in-depth design of a nuclear plant, how could the TMI accident happen? At TMI, the defense-in-depth safety systems operated correctly but were shut down by qualified operators who misinterpreted the chain of events. The operators consciously turned off emergency cooling systems because they thought additional water would rupture the cooling system. The operators were convinced a valve was closed because a control panel light showed the valve had been given a signal to close. Although there were other indications that the valve was actually open, the operators continued to act to protect the system from additional water.

After TMI, the nuclear power plants have expanded their operator training programs. Plants have also modified their control room indicators, and have modified some plant equipment to prevent other accidents from occurring.

Another serious commercial power reactor accident occurred at the Chernobyl nuclear power plant in the Soviet Union. At Chernobyl, on April 26,1986, a nuclear power plant accident released large amounts of radioactive fission products to the environment.

The Chernobyl accident was caused by a combination of errors, deliberate failure to follow procedure and a poor design. The design of the Chernobyl reactor resulted in a very rapid increase in power after the water used to cool the core was lost. As a result, the pressure increased to the point that the reactor was blown apart. Such an accident is impossible at a U.S. PWR or BWR. In PWRs or BWRs, such a loss of water would have shut down the reactor.

Thirty-one people, all of whom were onsite emergency response personnel, died as a result of the accident. Two workers were killed by an explosion. Twenty-nine were killed by acute effects of radiation exposure, and 203 were hospitalized with radiation sickness. More than 36 hours elapsed after the accident before the 135,000 people living within a 20-mile (32 km) radius of the plant were told to evacuate.

Although a very large amount of fission products was released, no one outside the Chernobyl site boundary is reported to have suffered any symptoms of direct radiation sickness. The relatively low radiation doses offsite were the result of the fission products being carried high up into the atmosphere by the explosion and resulting fire.

Practice Exercise

26. The two main safety objects of nuclear power plant design are to contain ___________________ and to remove _________________________ generated by the reactor.

27. The three fission product barriers designed into a nuclear power plant are_________________, _________________, and _____________________.

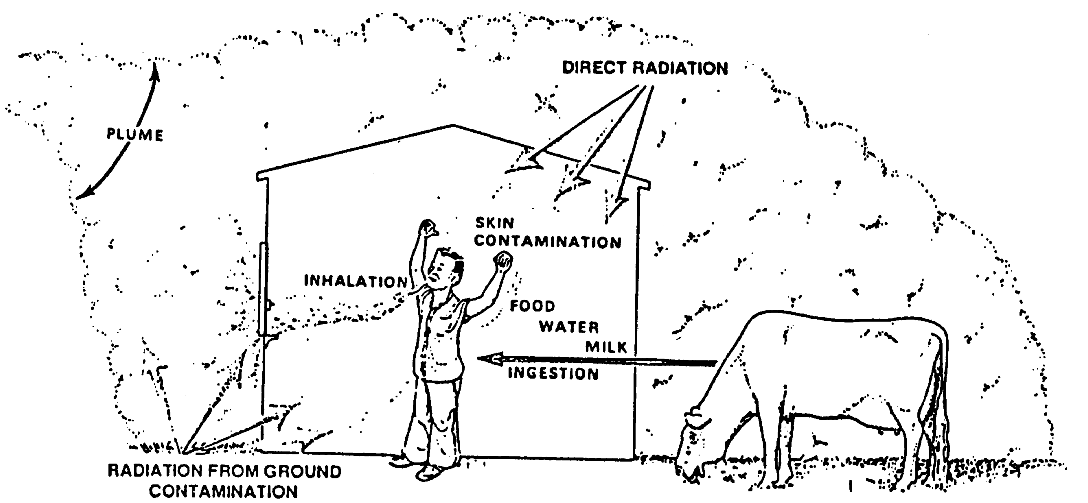
OFFSITE PROTECTIVE ACTIONS

Despite the extensive safety measures designed into each nuclear power plant, government emergency preparedness agencies require yet another degree of protection for the public. This extra step, known as "Beyond Defense-in-Depth," is intended to protect the public from the release of hazardous amounts of radioactivity from a nuclear power plant. Plant operators, as well as the federal government and the local states and counties, are required to maintain emergency plans to deal with the following radiological hazards:

- Direct exposure to radiation from a **plume** of airborne radioactive material or from radioactive material deposited on the ground.

- Internal or external contamination caused by direct contact with the plume.

- Ingestion of radioactive material.

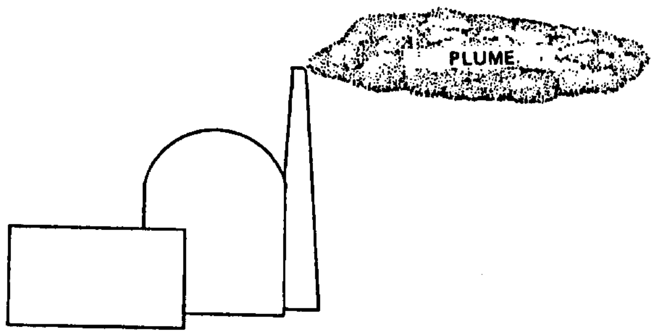


Radiation Dose Pathways

Plume Exposure

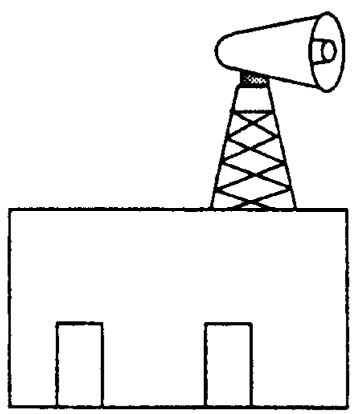
A **plume** is an airborne cloud of radioactive gases, particles and/or vapors released from a plant. In many ways, the risk from a radioactive plume is similar to that from any cloud of hazardous materials. Members of the public should avoid being immersed in the hazardous cloud, breathing from the hazardous cloud, and entering areas contaminated by the cloud's passage. Obviously, the major difference is that a plume released as a result of a major reactor accident will be radioactive and not hazardous in other ways (e.g., flammable, corrosive).

The plume could be very hot and rise as it leaves the plant (e.g., as steam rises), as was the case for the Chernobyl accident. If this is the case, the population close to the plant may be spared many of the consequences as the plume passes overhead. The plume could be released continuously over a long period, or it could be released as a very short puff As the radioactive plume (cloud) moves away from the reactor site, radioactive materials will settle out and deposit on the ground, trees, people, etc. This is called ground contamination.



Plume

Extensive communication networks have been established to notify the public near a nuclear power plant accident. Upon notification, members of the public should listen carefully to their Emergency Broadcast System (EBS) radio or television stations to learn of the appropriate actions to be taken.



Notification Siren

In areas near operating nuclear power plants, provisions have been made to provide the public with information on what actions they should take in the event of an emergency and how they will be notified. If you live near a plant, you should obtain and study this material which is available through the county emergency planning department.

There are four levels of emergencies covered by the emergency plans at nuclear power plants. Each level requires specific actions to be taken by the plant operator and offsite officials. These levels, in order of increasing severity, are:

- Unusual Event.
- Alert.
- Site Area Emergency.
- General Emergency.

Unusual Events are events that are uncommon but, do not represent a threat to the plant or public. There are about 200 unusual events a year.

Alerts are the result of events that should be monitored closely. They also do not represent a threat to the public. There are about 10 alerts a year.

Site Area Emergencies are major failures but immediate actions by the public are not needed. At this level of emergency, the public would normally be notified and instructed to stand by for further instructions.

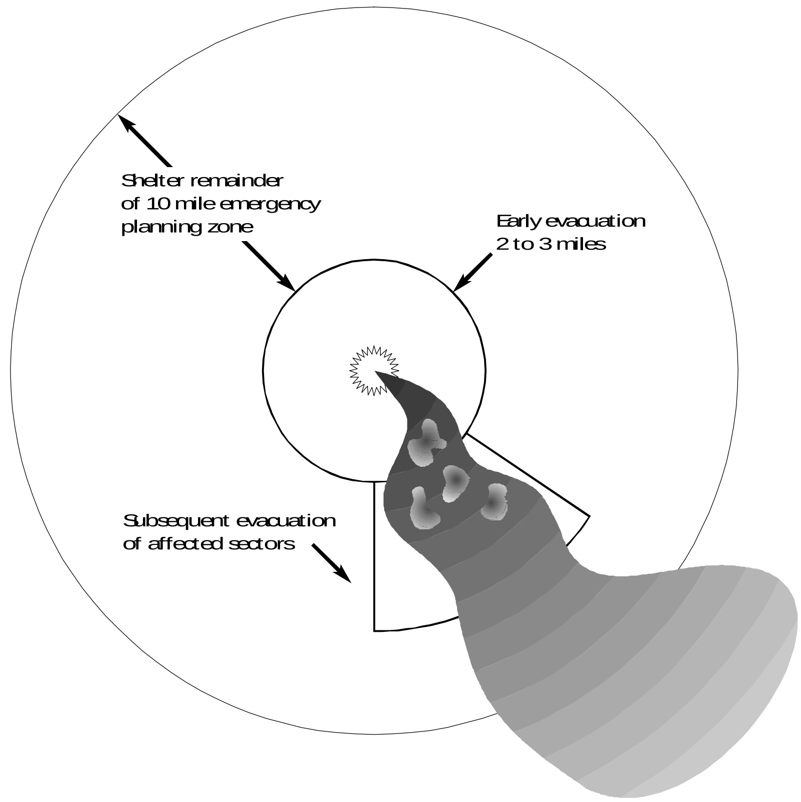
General Emergencies are very severe accidents that call for immediate protective action by the public. In the event of a General Emergency, the actions to be taken have been preplanned. While these events represent a major threat, a major release of radioactive material would not necessarily take place. Actions taken are precautionary. Under current federal regulations, Three Mile Island would have been a general emergency.

It is very important to realize that the emergency plans for each site are unique. The plans were developed to take into consideration local conditions and they must be studied and followed if you live near a plant. If instructions are given to take a protective action, they should be followed **promptly**.

Typical recommended protective actions following a severe nuclear power plant accident (general emergency) would be to:

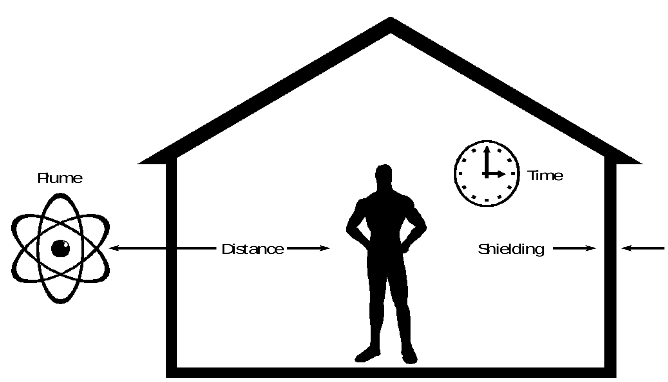
- Evacuate areas close (2 to 3 miles or 3 to 5 km) to the plant in all directions and a section downwind out to 10 miles (i.e., a key hole effect).
- Shelter elsewhere within approximately 10 miles (16 km).

These actions would be recommended, if possible, **before** a major release of radioactive material. After the release, evacuation of additional sectors might be recommended if indicated by radiological monitoring in those areas. If local conditions prevent evacuation, shelter may be advised.



Protective Actions for Severe Nuclear Power Plant Accidents

In rare cases, as an alternative to evacuating, sheltering in a home, office or other building could provide protection just as sheltering following a nuclear detonation by a terrorist attack. As we will learn in Unit 4, a shelter would provide both distance and shielding between individuals and nuclear radiation. A home or building could similarly provide protection from the radioactive plume.



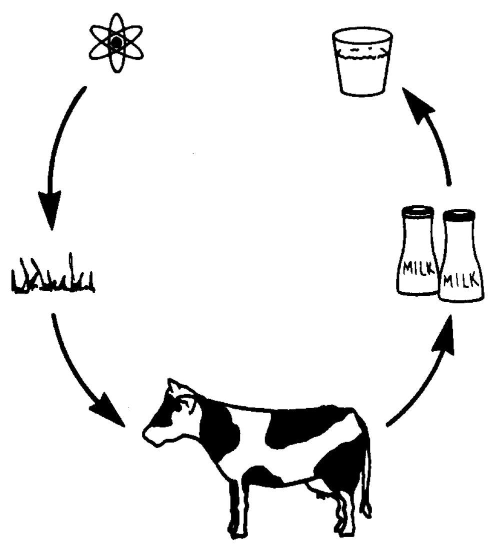
Contamination Exposure

Radioactive fission products can also present a hazard through direct contact with the exposed individuals. Contact with a plume can result in contamination of a person's clothing or skin. Airborne radioactive materials may also present an internal exposure hazard if inhaled by individuals exposed to the passing radioactive plume. Inhaled material, in addition to directly providing a dose, contains certain elements that concentrate in particular organs (e.g., lungs, bones, or thyroid) and thus become a special threat to those organs.

When taking shelter from a radioactive plume, one should take care to prevent unnecessary exposure to airborne radioactive material by closing windows and turning off air conditioners and ventilation fans. Additional protection actions may be recommended by the local authorities.

Ingestion Exposure

Radioactive material from a radioactive plume may be ingested by man from a variety of pathways. For example, radioactive particles deposited on the ground may be eaten by grazing cattle whose meat or milk is consumed by man.



Ingestion Pathway Example: Milk

The public should heed official warnings to prevent this sort of exposure. In addition, state and local officials will conduct tests to determine if there are problems with local food, water or milk supplies.

Special protective actions are available to prevent exposure to radioactive iodine. Iodine is a major fission product which may be released during nuclear power plant accidents. Iodine is of particular interest because it tends to concentrate in the thyroid gland, just as iron concentrates in blood or calcium in bone.

An amount of radiation exposure which would be of little concern if spread throughout the entire body, may become a problem if concentrated in the thyroid. To prevent this exposure, you may be advised to take a **thyroid blocking agent**.

A thyroid blocking agent is a pill, typically containing potassium-iodide. The thyroid blocking agent contains non-radioactive iodine which, when taken before or immediately after exposure to radioactive iodine, saturates the thyroid with non-radioactive iodine. Since additional iodine will not be absorbed by the thyroid, any radioactive iodine subsequently taken up by the body will remain spread throughout the body and will be quickly excreted.

It must be understood that use of a thyroid blocking agent is not an adequate substitute for prompt evacuation or sheltering by the general population near a plant in response to a severe accident. Ingestion of a thyroid blocking agent will serve only to reduce the dose to the thyroid caused by intake of radioactive iodine. The primary risk to the population from a severe accident is whole body dose, not the dose to the thyroid.

Practice Exercise

28. Emergency plans are developed for nuclear power plants to address the following three radiological hazards: ____________________, ________________________, and ___________________________.

29. In areas near operating nuclear power plants, information on what actions the public should take following an accident and how they will be notified has been prepared. If you live near a plant, you should obtain and _________________ this material.

30. Although events representing a general emergency represent a major threat, a major release of radioactive material would not normally take place. Actions taken are _______________________.

31. When notified to take protective actions following a nuclear accident, the instructions should be followed ________________________.

32. In the event if an accident at a nuclear power plant, special protective actions may be taken to prevent exposure to radioactive _______________________________.

UNIT 3 REVIEW

This unit described the hazards and protective measures associated with a nuclear power plant accident. The defense-in-depth approach used in designing U.S. nuclear plants ensures that most accidents will not result in the release of radioactive materials. Even in the accident at Three Mile Island, the vast majority of radioactive material was contained. The accident at Chernobyl released much larger quantities of radioactive material than were released during the Three Mile Island accident.

Each U.S. nuclear plant has an emergency plan as do the Federal government and the state, counties, and local jurisdictions. These plans describe actions to minimize public exposure that could result from a serious accident. The plans address exposure to radioactive plumes and exposure from ingesting radioactive material into the body.

UNIT 3 REVIEW QUESTIONS

Answer the following questions to review your knowledge of this unit. Read each question carefully and circle the correct answer.

1. Which one of the following components distinguishes a nuclear power plant from a coal or oil burning plant?

   a. Turbine

   b. Condenser

   c. Cooling tower

   d. Pump

   e. Heat source

2. A power plant's condenser may be cooled through the use of a cooling tower or:

   a. Water from a nearby lake, river, ocean or man-made reservoir

   b. Steam exhausted from the turbine

   c. Refrigeration systems

   d. Direct evaporation

3. A cooling tower is:

   a. A large concrete structure built to contain the nuclear reactor and prevent the release of fission products

   b. A component of nuclear power plants only

   c. A structure used to prevent harmful temperature increases in lakes and rivers

   d. A large hollow concrete structure filled with water

4. The fuel used at nuclear power plants is made of:

   a. Fission products

   b. Uranium

   c. Fossil fuels

   d. Neutrons

5. When an atom of nuclear fuel is struck by a free neutron, it fissions yielding:

   a. Additional free neutrons, heat, and fission products

   b. Heat, fission products, and plutonium

   c. Fission products, radiation, and plutonium

   d. Plutonium, heat, and additional free neutrons

6. Which of the following is NOT a barrier to the release of fission products?

   a. Fuel cladding

   b. Reactor vessel and primary coolant system

   c. Containment building

   d. Cooling tower

7. Upon notification of a nuclear power plant accident, individuals should:

   a. Evacuate immediately

   b. Seek a shelter

   c. Call the local emergency program manager for instructions

   d. Listen to the EAS radio or TV stations to learn of appropriate protective actions

8. If a nuclear power plant accident results in the release of a radioactive plume, an individual 30 miles (48 km) downwind should be concerned about:

   a. Direct exposure to radiation from the passing plume

   b. Direct exposure to radiation from fallout

   c. Contaminated food and water

   d. The need for sheltering or evacuation

9. Fuel rods are grouped side-by-side to form a:

   a. Control rod

   b. Fuel cladding

   c. Fuel assembly

10. A thyroid blocking agent protects the user from:

    a. An over-active thyroid

    b. External radiation sources

    c. Dispersal of radioactive iodine throughout the body

    d. Concentration of radioactive iodine in the thyroid

UNIT 3
REVIEW ANSWER KEY

1. e
2. a
3. c
4. b
5. a
6. d
7. d
8. c
9. c
10. d